SUMMARY OF THE ACTIVITY IN PLASMA PHYSICS AT THE UNIVERSITY OF IOWA UNDER N.A.S.A. GRANT NGL-16-001-043 FROM JUNE 1970 TO THE PRESENT

(Annual Status Report, June 1971)

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The following report is divided into two parts. Part A consists of abstracts of theoretical papers published and submitted during the above period. Part B is abstracts from the space physics half of the program.

Part A. Theoretical Abstracts

1. Electrical Conductivity of Weakly Turbulent Plasmas
Y. H. Ichikawa (visitor from Nihon University, Tokyo) and K. Nishikawa
Physics of Fluids 14, 569 (1971).

The static electric conductivity of weakly turbulent plasmas has been examined on the basis of a kinetic equation for the linear response to the one-particle distribution function. Within the regime of neglecting the mode-coupling terms, the high-frequency turbulent fluctuations associated with the electron plasma wave give rise to a modification of the ordinary collisional conductivity through the adiabatic interaction between the particles and the turbulent fluctuations. On the other hand, the low-frequency turbulent fluctuation due to the ion oscillation mode determines the relaxation process in the system through the resonant interaction, and gives rise to a finite conductivity even in the collisionless plasmas.

2. Effects of Bunched Ion Bursts on Apparent Nonlinear Ion Acoustic Waves
Y. H. Ichikawa (visitor from Nihon University, Tokyo)
Physics of Fluids 13, 2541 (1970).

The bunching effects of ions at the excitation grid in a typical ion acoustic wave experiment are examined by

applying the generalized quasilinear theory of Al'tshul and Karpman to a simple model of the grid-plasma system. The resulting bunched ion bursts exhibit amplitude modulation at a distance far from the grid. The characteristics of this amplitude modulation appear to be similar to the recently observed results of Sato, Ikezi, Takahasi and Yamashita, who interpreted their results in terms of nonlinear Landau damping of ion acoustic waves.

3. Discrete Spectra and Damped Waves in Quasilinear Theory
G. Vahala and D. Montgomery
Journal of Plasma Physics 4, 677 (1970).

The consequences of the quasilinear equations are explored. Particular attention is paid to the differences between the one-dimensional and the two- and three-dimensional cases, and to the differences between the cases of discrete and continuous wave-number spectra. The possibilities of and problems associated with including damped waves are treated. The relation between conservation laws and the 'resonance approximation', in which the limit of zero growth rate for the unstable waves is taken at finite times, is clarified. Numerical solutions for the one-dimensional case with finite growth rate are presented.

4. Comment on Negative Diffusion Coefficients in Quasi-linear Theory
D. Montgomery and S. Bodner (LRL, Livermore)
Journal of Plasma Physics 5, 131 (1971).

A recent paper by Klozenberg and Bernstein is commented upon. It is argued that improper treatment of the perturbed electron distribution for damped waves has led to a diffusion-type equation with negative diffusion coefficient.

5. Brownian Motion from Boltzmann's Equation
D. Montgomery
(accepted for publication by Physics of Fluids)

Two apparently disparate lines of inquiry in kinetic theory are shown to be equivalent: (1) Brownian motion as treated by the (stochastic) Langevin equation and Fokker-Planck equation; and (2) Boltzmann's equation. The method is to derive the kinetic equation for Brownian motion from the Boltzmann equation for a two-component neutral gas by a simultaneous expansion in the density and mass ratios.

6. Relation of Langevin's Equation to Boltzmann's Equation in the Theory of Brownian Motion
D. Montgomery
Proc. Conf. on Statistical Mechanics (I.U.P.A.P.)
Chicago, Ill., March 29-April 2, 1971, pp. IV.1 - IV.5.

[no abstract]

7. Theory of the Unmagnetized Plasma
D. Montgomery
(to be published by Gordon and Breach, 1971)

[book; no abstract]

[This book was completed in September, 1970; a detailed synopsis was presented in last year's proposal, and copies were mailed to N.A.S.A. in September, 1970.]

8. Parametric Amplification of Alfvén Waves
G. Vahala and D. Montgomery
(accepted for publication by Physics of Fluids)

A calculation describing the parametric amplification of Alfvén waves in a uniform, perfectly-conducting, magnetohydrodynamic fluid is reported. The calculation has been motivated by a recent experiment of Lehane and Paoloni. A magnetically-supported uniform column of the magnetohydrodynamic fluid is imagined to be subjected to an externally-imposed, sinusoidally-varying, magnetic field which can be idealized as spatially-uniform. It is shown that a certain class of Alfvén waves which have an axial wavelength long compared to the radius of the column can be parametrically amplified in the case where their frequency and the modulating frequency satisfy certain integer quotient relations. The mathematical behavior is determined by Mathieu equations.

9. Kinetic Theory of a Two-Dimensional Magnetized Plasma
G. Vahala and D. Montgomery
(submitted to Journal of Plasma Physics)

Several features of the equilibrium and non-equilibrium statistical mechanics of a two-dimensional plasma in a uniform d.c. magnetic field are investigated. The calculations have been motivated by the recent derivation of Bohm's diffusion coefficient given by Taylor and McNamara for this system. The charges interact only through electrostatic (logarithmic) potentials. The problem is considered both with and without the guiding center approximation. With the guiding center

approximation, an appropriate Liouville equation and BBGKY kierarchy predict no approach to thermal equilibrium for the spatially uniform case. For the spatially non-uniform situation, a guiding-center "Vlasov" equation is discussed and is solved in special cases. The most interesting features of thermal equilibrium theory (with and without the guiding center approximation) are (1) a collapse of the system above a critical value of the plasma parameter; and (2) a divergence in the electric field fluctuation spectrum (minus the self-energy terms) for small plasma parameter and very large systems. For the non-equilibrium, non-guiding center case, a Boltzmann equation and a Fokker-Planck equation are derived in the appropriate limits. The latter is more tractable than the former, and can be shown to obey conservation laws and an H-theorem, but contains a divergent integral which must be cut off on physical grounds. Several unsolved problems are posed.

10. On the Free-Energy Expansion of a Classical Coulomb Gas. I.
Fernando del Rio and Hugh E. DeWitt (visitor from LRL, Livermore)
(submitted to Revista Mexicana Fisica)

The expansion of the free-energy in terms of nodal diagrams is carried explicitly and analytically up to fifth order for a classical system of charged particles in a neutralizing background. An approximation is introduced to avoid the expansion in terms of the plasma parameter, and thus also avoiding the divergences that such an expansion introduces. The same approximation is used to investigate the high-density limit of the low-density expansion.

11. On the Free-Energy Expansion of a Classical Coulomb Gas. II: The Nodal-Ring Term
Hugh E. DeWitt (visitor from LRL, Livermore) and Fernando del Rio
(submitted to Revista Mexicana Fisica)

The nodal expansion for the free-energy of a classical Coulomb gas, introduced by Abe, Friedman and Meeron, is used to produce results which are hopefully meaningful for intermediate values of the plasma parameter. The results how no divergences and the calculation of the free energy is reduced to a quadrature. The connection of this result to the nodal expansion of the pair distribution function is shown explicitly.

Part B. Ionospheric and Magnetospheric Abstracts

12. Recent Rocket Measurements of AC Electric and Magnetic Fields in the Ionosphere
S. D. Shawhan and D. A. Gurnett
Plasma Waves in Space and Laboratory, Vol. 2,
J. O. Thomas and B. J. Lankmark, eds., Edinburgh University Press, Edinburgh, 1970.

[no abstract]

13. Conjugate Photoelectron Impact Ionization
S. D. Shawhan, L. P. Block, and C.-G. Falthammar
J. Atmos. Terr. Physics, 1970.

The exchange of photoelectrons between ionospheres in a matter of minutes rather than at the slow ambipolar speed is discussed. It is shown that the electron density may be affected by secondary processes resulting from the conjugate photoelectron flux but not by the flux itself.

The flux spectrum of conjugate photoelectrons throughout the day at the solstices for minimum solar activity is calculated for 55° N. geographic latitude over Europe, using a method previously employed by NISBET. Summer escaping flux values range up to 9×10^{12} electrons m^{-2} sec^{-1} and winter values to 5×10^{12} electrons m^{-2} sec^{-1}. Compared at specific solar zenith angles the computed values are in good agreement with recent satellite measurements. Approximately half of this flux is lost by Coulomb collisions along the field line path. The resulting flux arriving at the local ionosphere produces ionization by inelastic collisions in the atmosphere. This additional ionization is about 3% of the ionization from local processes at summer noon and 48% at winter noon. During winter nighttime this conjugate photoelectron ionization can be significant for several hours.

Although small in magnitude, this additional ionization should systematically modify the summer total electron content depending on geographic location. The large seasonal differences in the relative impact ionization may explain in part the F-layer seasonal anomaly. This source may be important for maintaining and causing enhancements in the winter nighttime ionosphere.

14. An Experimental Study of VLF Mode Coupling and Polarization Reversal
P. Rodriguez and D. A. Gurnett
J. Geophys. Res., 76, 960, 1971.

Below the proton gyrofrequency, both polarization reversal and mode coupling of the right and left hand modes

of propagation can occur. In this paper an experimental study of polarization reversal and mode coupling of electron and proton whistlers is presented. The occurrence of polarization reversal for a whistler signal observed in the ionosphere is indicated by the presence of a proton whistler. Mode coupling between the right and left hand modes of propagation is indicated by the occurrence of both electron and proton whistler signals at the same frequency.

Mode coupling is observed to occur most frequently over a range of about 35° - 55° magnetic latitude. Below about 35° magnetic latitude, polarization reversal is the predominant effect, whereas above about 55° magnetic latitude neither mode coupling nor polarization reversal occur and proton whistlers are not observed. These results are compared with existing theories to explain this latitude dependence.

15. Theory of the Injun 5 VLF Poynting Flux Measurements
S. R. Mosier, and D. A. Gurnett
J. Geophys. Res., 76, 972, 1971.

This paper presents the theory of the VLF Poynting flux measurement technique used on the Injun 5 satellite. This technique consists of using one electric antenna and one magnetic antenna, both oriented perpendicular to the geomagnetic field and to each other, to determine the direction of the VLF Poynting flux up or down the geomagnetic field. The conditions for which the Poynting flux direction determinations are valid are considered, including the effects of errors in the magnetic orientation of the spacecraft and the simultaneous presence of many waves.

16. Poynting Flux Studies of Hiss with the Injun 5 Satellite
S. R. Mosier
J. Geophys. Res., 76, 1713, 1971.

A study of very-low-frequency hiss emissions in the region 677 to 2528 km and 35° to 75° invariant latitude (in the northern hemisphere) using the Injun 5 Poynting flux measurement technique is presented. Downgoing ELF hiss is observed over the entire region of altitude-invariant latitude space under study, whereas ELF hiss having an upward-directed net Poynting flux is only observed at invariant latitudes below about 60°. A new propagation phenomenon is proposed in which downgoing ELF hiss may propagate across the plasmapause boundary to lower latitudes and become subsequently reflected and trapped within the plasmasphere. Measurements

indicate that at least part of the VLF hiss which is observed by the Injun 5 satellite must be generated above the Injun 5 altitude range. A new type of sub-auroral-zone VLF hiss has been observed called mid-latitude hiss.

17. Whistlers with Harmonic Bands Caused by Multiple Stroke Lightning
R. R. Shaw and D. A. Gurnett
J. Geophys. Res., 76, 1851, 1971.

Whistlers received with the Injun 5 satellite are frequently observed to have bands with decreased signal amplitude at equally spaced frequency intervals. The frequency spacing between the bands is typically about 10 to 30 Hz. As many as 30 such bands have been observed on a single whistler.

Because the frequency spacing of these bands is comparable to the gyrofrequency of several types of positive ions found in the ionosphere (particularly O^+ or N^+) it was initially thought that these bands may be produced by a hot plasma effect resulting from wave-particle interactions at harmonics of the ion gyrofrequency. Subsequent investigations, prompted by a suggestion made by Dr. R. L. Dowden at the spring 1970 URSI meeting, have shown that the bands are instead due to double or multiple strokes in the initial lightning discharge which result in destructive interference of the whistler signal at equally spaced frequency intervals. The frequency spacing between the interference bands is given by the inverse of the time interval between the lightning strokes. This simple explanation for these bands accounts for a number of peculiar characteristics which could not be accounted for with the gyrofrequency harmonic interaction hypothesis.

18. Color Spectrograms of VLF Poynting Flux Data
D. A. Gurnett, S. R. Mosier, and R. R. Anderson
J. Geophys. Res., 76, 3022, 1971

This paper discusses a new method of processing the VLF electric and magnetic field data from the Injun 5 satellite to produce color frequency-time spectrograms with the color indicating the Poynting flux direction, up or down the geomagnetic field. The Poynting flux sensing technique used on Injun 5 employs one electric antenna and one magnetic antenna both oriented perpendicular to the geomagnetic field and to each other. With this antenna geometry the Poynting flux direction, up or down the geomagnetic field, can be determined from the cross-correlation between the electric and magnetic field signals. The technique used to process these

signals employs a new type of spectrum analyzer/cross-correlator to determine the cross-correlation between the electric and magnetic field signals as a function of frequency and time. These data can be displayed as a two color frequency-time spectrogram using appropriate display techniques. A survey of complex VLF radio noise phenomena analyzed using this technique is presented.

19. Double Probe Measurements of DC Electric Fields with the Injun 5 Satellite
D. P. Cauffman and D. A. Gurnett
J. Geophys. Res., (accepted for publication), 1971.

This paper reports on the operation and results of the double-probe DC electric field experiment on the low altitude polar orbiting Injun 5 satellite. At middle and low latitudes, where the convection electric field is generally very small, the operation of the double-probe electric field antenna is investigated by comparing measured electric fields with the $\vec{V}_s x \vec{B}$ electric field generated by the satellite motion through the ionosphere. Errors caused by sunlight shadows on the probes, wake effects, and antenna impedance variations are discussed.

At high latitudes convection electric fields greater than 30 mV/meter, and sometimes greater than 100 mV/meter, are frequently observed in the auroral zone. A common feature of these high latitude convection fields is the occurrence of abrupt reversals in the east-west convection velocity at auroral zone latitudes. For dusk-dawn local times, these reversals generally correspond to an east-west flow away from the sun on the high latitude side of the reversal and toward the sun on the low latitude side. Over the polar region above the auroral zone the convection velocity is usually small. At the plasmapause/light ion trough boundary small, 10 to 20 mV/meter, electric field perturbations are sometimes observed, corresponding to generally westward convection outside the plasmasphere.

At high altitudes, above about 1500 km, over the auroral zone/polar cap regions irregular electric field "noise" with amplitudes from 10 to 30 mV/meter is consistently observed. Possible explanations of the high altitude electric field noise are discussed.

Results are consistent with measurements using the barium cloud drift technique. Convection observed is also compared with models of magnetospheric structure and with models of substorms and aurorae.

20. On the Distribution of Plasmas and Electric Fields Over the Auroral Zones and Polar Caps
L. A. Frank and D. A. Gurnett
J. Geophys. Res., (submitted for publication), 1971.

Simultaneous observations of DC electric fields and low-energy charged particles at low altitudes over the earth's auroral zones and polar caps were obtained with the satellite Injun 5. Several of the principal results for several passes of the satellite through the evening and dawn local time sectors are summarized as follows.

1. The most prominent features of the convection electric fields are reversals located at high magnetic latitudes in the dawn and evening sectors.
2. The east-west convection velocity is usually anti-sunward at latitudes above the reversal boundary and sunward at latitudes below the reversal boundary.
3. The convection electric field reversals in the dawn and evening sectors are coincident with the 'trapping boundary' for energetic electrons $E > 45$ keV. This trapping boundary is observationally identified with the high-latitude termination of measureable electron intensities as viewed with a detector with generous geometry factor. This trapping boundary is not synonymous with the high-latitude limit of durable trapping, i.e., an electron with these energies is not necessarily able to execute a complete longitudinal drift motion.
4. Over the polar caps the convection velocities are small, or below the instrumental threshold of typically ~ 0.75 kilometers $(\text{sec})^{-1}$, relative to the convection velocities in the vicinity of the reversals.
5. The polar cap region is characterized by an absence of measureable low-energy proton and electron intensities.
6. Inverted 'V' precipitation events, which are characterized by increasing average electron energies to a peak energy and a subsequent decrease in energy as the satellite passes through this intense precipitation event, are located near or at the convection field reversals (and hence also the trapping boundaries) or within regions of measurable convection electric fields poleward of the trapping boundary.
7. Field-aligned electron angular distributions occur at and above the trapping boundary and within the inverted 'V' precipitation events.

8. Diffuse precipitation zones of electron and proton intensities with spectrums similar to those observed in the near-earth plasma sheet are located at latitudes below the trapping boundary and within the region of sunward convection velocities. The ratios of intensities at pitch angles $\alpha = 0°$ to those measured at $\alpha = 90°$ (Northern hemisphere) are usually $\lesssim 1$.
9. During a magnetic substorm the overall configuration of the convection velocities and plasma regions remained similar to those observed during quiescent periods except that convection velocities and particle intensities increased and the locations of these phenomena in magnetic latitude varied.

These observations are interpreted in terms of a magnetospheric model as deduced from plasma observations in the distant magnetosphere and in terms of essential elements for any credible theory of auroral arcs, in particular those associated with inverted 'V' precipitation bands.

21. VLF hiss and Related Plasma Observations in the Polar Magnetosphere
D. A. Gurnett and L. A. Frank
J. Geophys. Res., (submitted for publication), 1971.

This paper presents a study of auroral zone VLF hiss and low-energy charged particle observations with the Injun 5 satellite. The results of this study provide the first direct verification of the association between auroral zone VLF hiss and intense fluxes, 10^4 to 10^7 electrons $(cm^2\text{-}sec\text{-}sr\text{-}eV)^{-1}$, of low-energy electrons with energies on the order of 100 eV to several keV. On the dayside of the magnetosphere, these low-energy electrons are identified with the dayside polar cusp region observed at higher altitudes with the IMP-5 satellite. At other local times, through the dawn and dusk regions and into the nightside of the magnetosphere, the VLF hiss and low-energy electron precipitation regions are believed to correspond to the extension of the dayside polar cusp into the distant plasma sheet and downstream magnetosheath on the nightside of the magnetosphere. Intense fluxes of upgoing electrons are often observed in a narrow latitudinal band near the low-energy electron precipitation bands. These upgoing electrons are believed to be associated with another type of VLF emission called a saucer, which is frequently observed with Injun 5.

On the basis of present models, the observed VLF hiss intensities cannot be accounted for by incoherent

Cerenkov radiation from the observed electron fluxes, indicating that a coherent plasma instability mechanism is involved in some, if not all, of the VLF hiss generation. A model for the generation regions of VLF hiss and saucer emissions is discussed.